Mechanical Design of a Soft X-Ray Self-Seeding Monochromator for LCLS-I

K. Chow, L. N. Rodes, T. Stevens (LBNL),
D. Cocco, G. Gassner, J. Hastings, P. Montanez, D. Ratner (SLAC), U. Flechsig (PSI)

Abstract

Self-seeding shows promise as an effective approach to narrow the SASE bandwidth of Free Electron Lasers. Hard X-ray self-seeding has been previously demonstrated at LCLS using a diamond monochromator instrument. Recently X-ray self-seeding was also demonstrated at soft X-ray energies (from 500 to 1000 eV) using a grating-based monochromator. This grating-based monochromator is a novel two-part design that is spatially interleaved with chicane magnets and designed for compactness in order to mount onto a single existing undulator girder.

Introduction

The soft x-ray self seeding (SXRSS) project aims to improve on delivered energy bandwidth for free electron lasers (FELs) by utilizing photons from an upstream set of FEL undulators as a seed for the downstream portion of the FEL. SXRSS at LCLS-I has demonstrated an increase in peak brightness by 2 to 5 times across a photon energy range of 500-1000 eV compared to self-amplified spontaneous emission (SASE).

SXRSS is a collaboration project between SLAC, Lawrence Berkeley National Laboratory (LBNL), and PSI. PSI is responsible for the optics, LBNL is responsible for monochromator mechanical design and fabrication, and SLAC is responsible for the chicane, overlap diagnostics and commissioning.

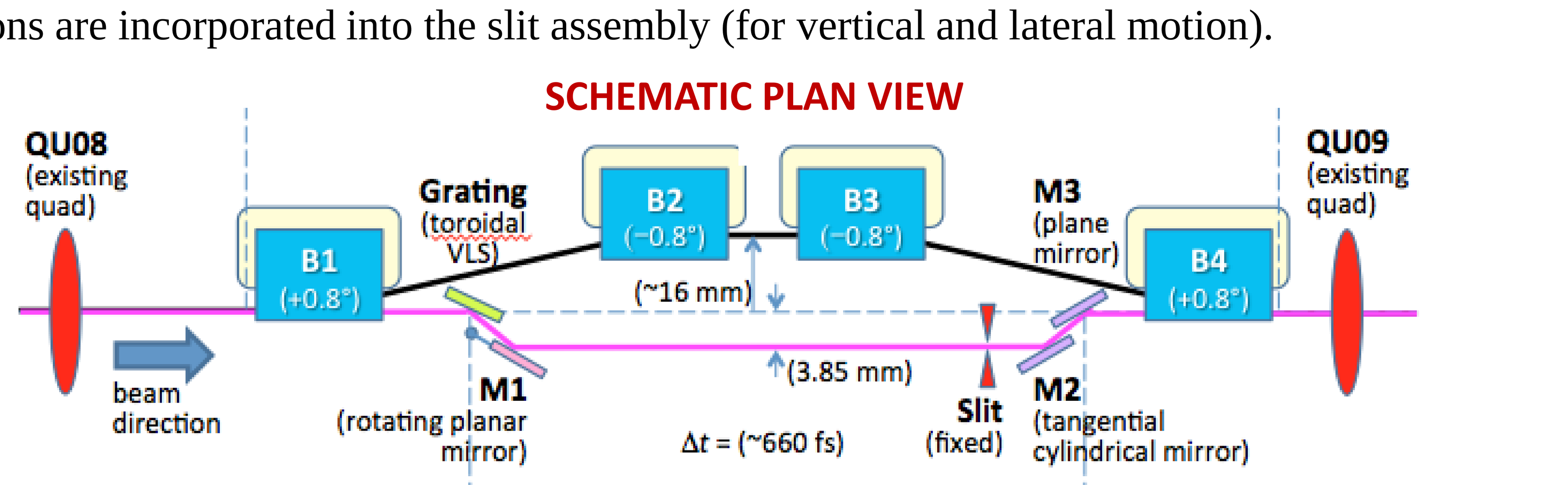
In this poster we present details of monochromator mechanical design and several key design and implementation challenges.

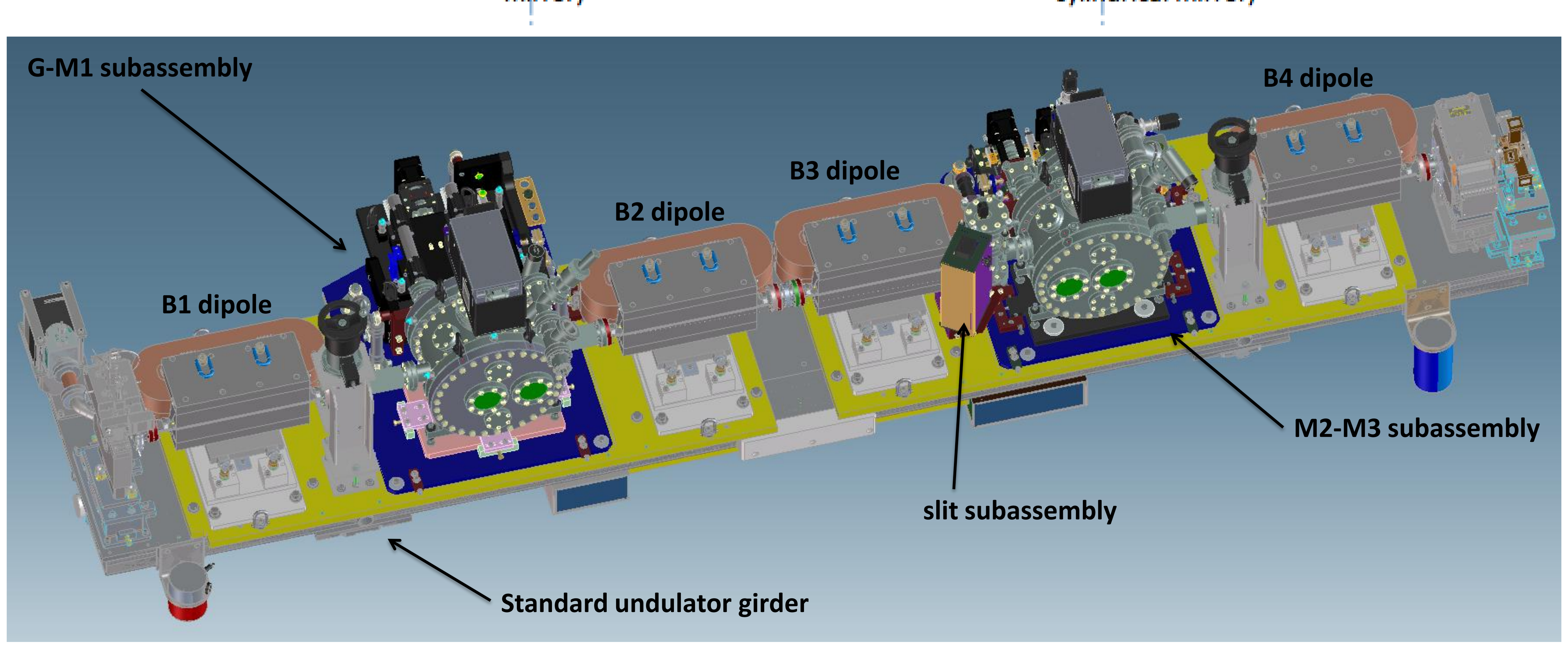
Monochromator Mechanical Design Concept

SXRSS is comprised of a set of 4 magnets to chicane the electron beam, a monochromator to select x-rays of interest for seeding, and a pair of beam overlap diagnostics to ensure alignment of electron and photon beams coming out of the chicane and monochromator.

The complete system is designed to fit within a single 3.4 meter long LCLS-I undulator section in order to preserve standard FEL operations. In order for the system to fit within its allocated space, the monochromator is separated into 2 subcomponents, each of which is interleaved with the chicane magnets. The grating-M1 mirror subassembly (G-M1) is positioned between the first and second chicane magnets, and the M2-M3 mirror subassembly (M2-M3) is located between the third and fourth chicane magnets. A small slit assembly resides just upstream of M2-M3.

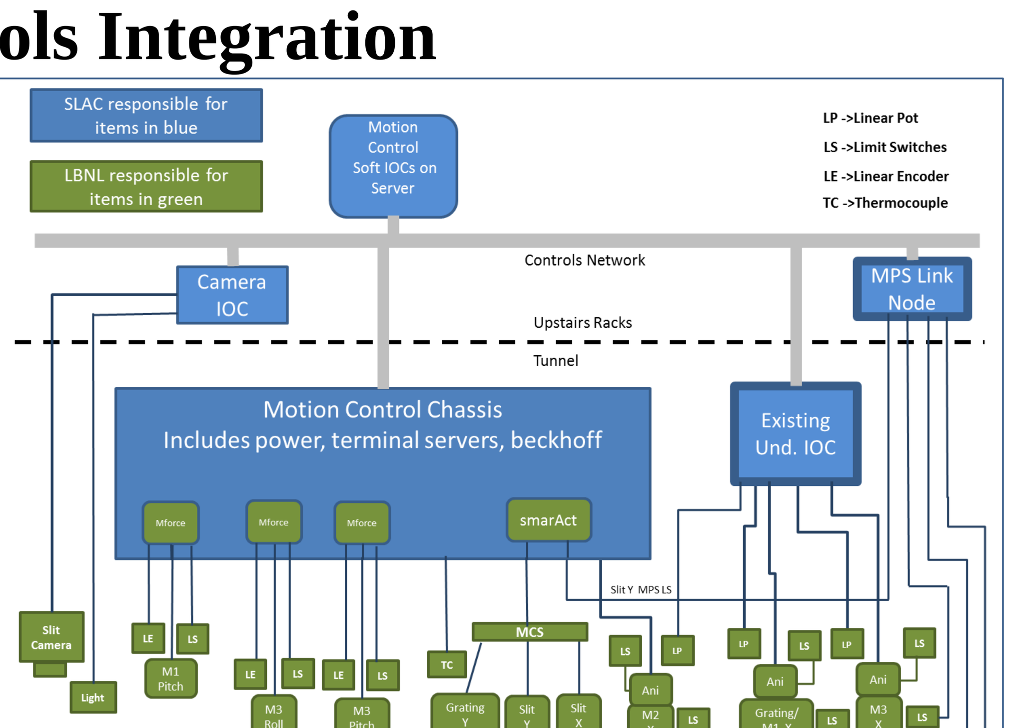
Photon energy selection in the monochromator is achieved via pitch angle adjustment of M1. This motion is the only one needed to scan the seeded FEL x-ray wavelength. Six other mirror motions are incorporated into the design for photon beam steering (to realign the photon beam with electron beam) and for full system retraction (to enable standard SASE operation). Two motions are incorporated into the slit assembly (for vertical and lateral motion).





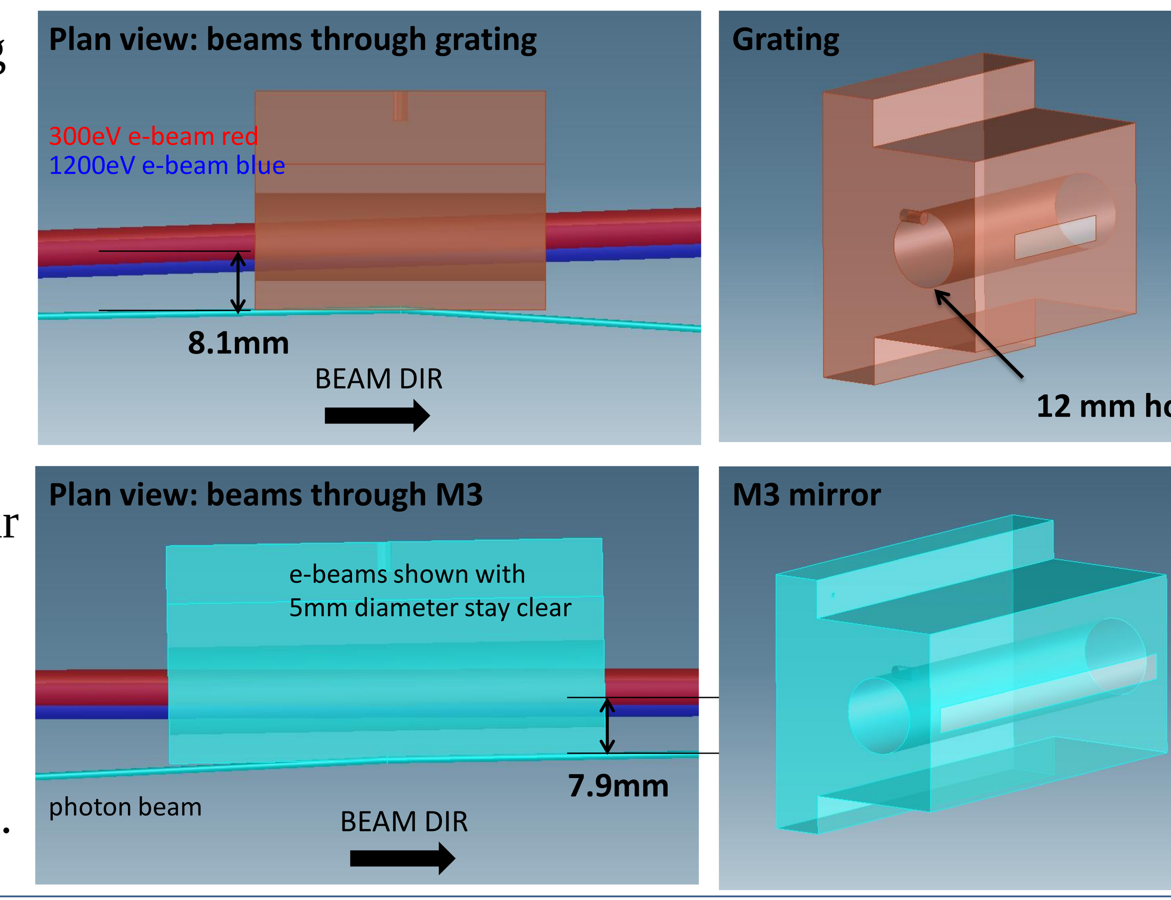
Motion Controls Integration

Nine separate motions (3 in vacuum) are required with associated limit switches and encoders, and additional control components are needed for a thermocouple, camera and camera lighting. We used existing undulator systems if possible and added to it as needed. SLAC held responsibility for controls integration, working closely with LBNL to ensure a system that provides sufficient machine protection and control.



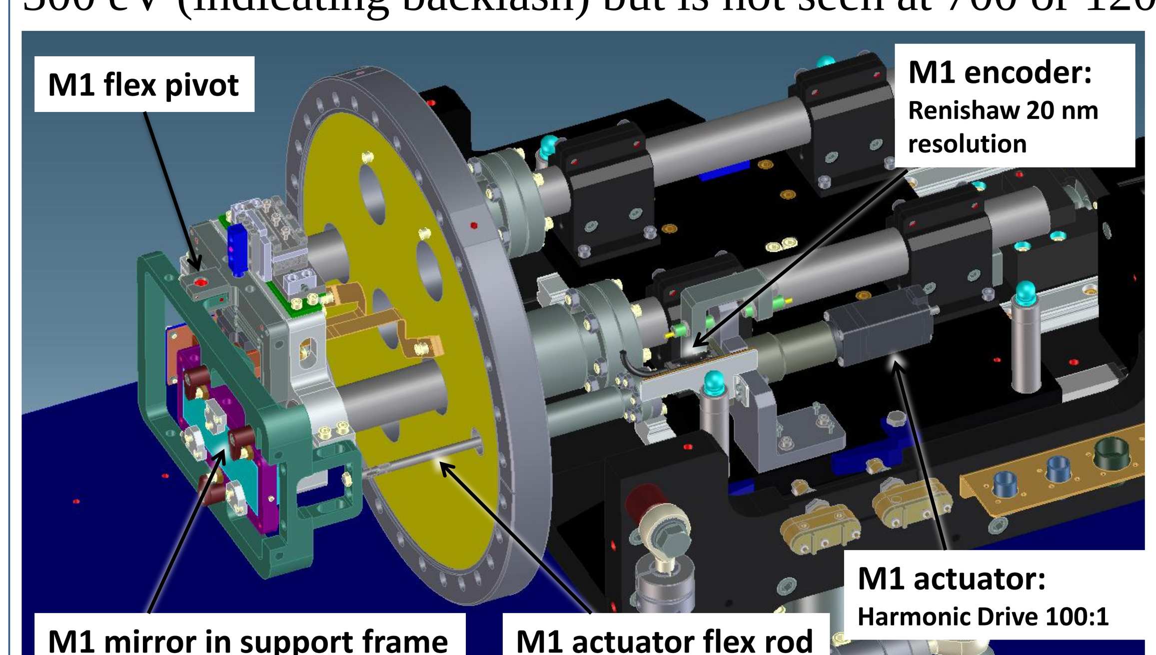
Proximity of Electron and Photon Beams

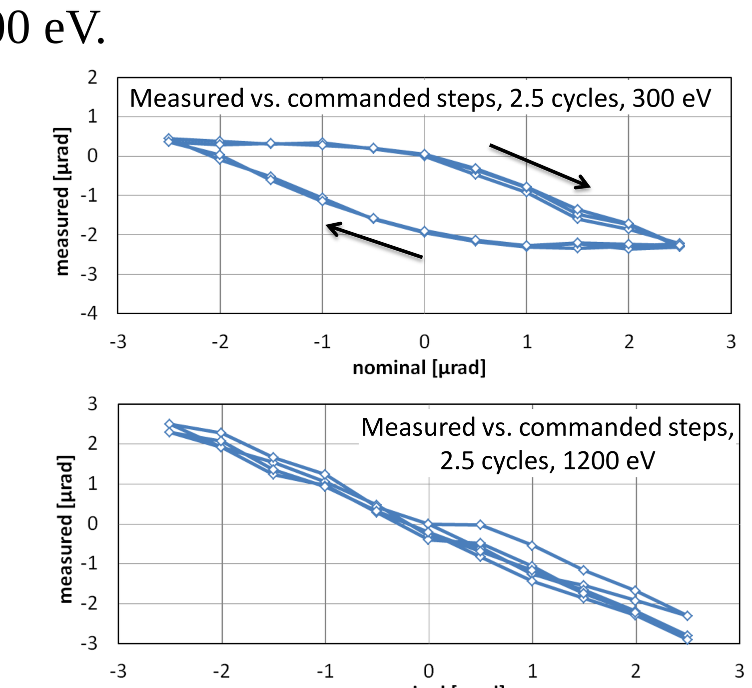
Fitting the system into one existing undulator section results in limited separation between electron and photon beams. In order to pass the electron beam, the first and last optical components (grating and M3 mirror) are designed with a hole in its substrate. The hole is sized to provide adequate stay-clear around the electron beam for the full energy range, and a 4 mm minimum thickness between the hole and optical face provides sufficient optical polishing support.

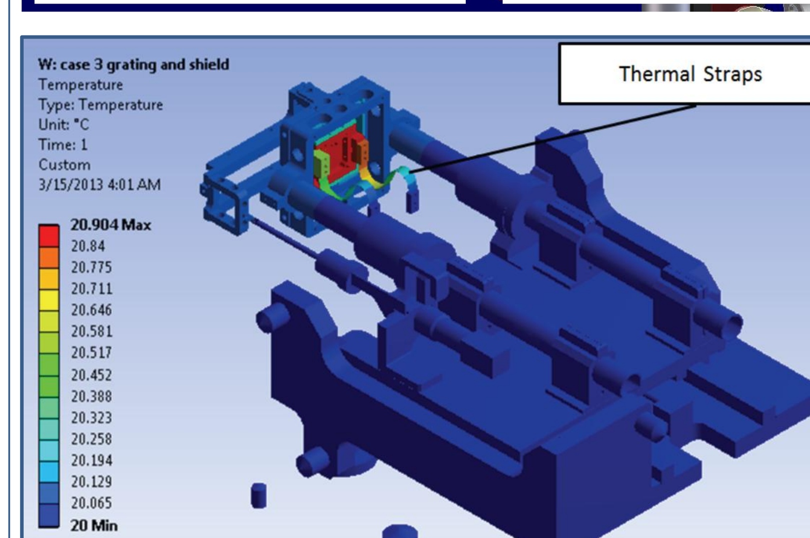


Photon energy selection

Selection of photon energy is accomplished through changing the pitch of M1. The mirror is mounted to a flexural pivot attached to the grating, and an actuated rod sets M1 pitch angle. Actuation is accomplished via an external stepper motor and geared to very fine steps using a harmonic drive. An external encoder provides position measurement. Measured steps indicate the resolved step size requirement of 0.5 μrad is met. Hysteresis is evident when measured at 300 eV (indicating backlash) but is not seen at 700 or 1200 eV.





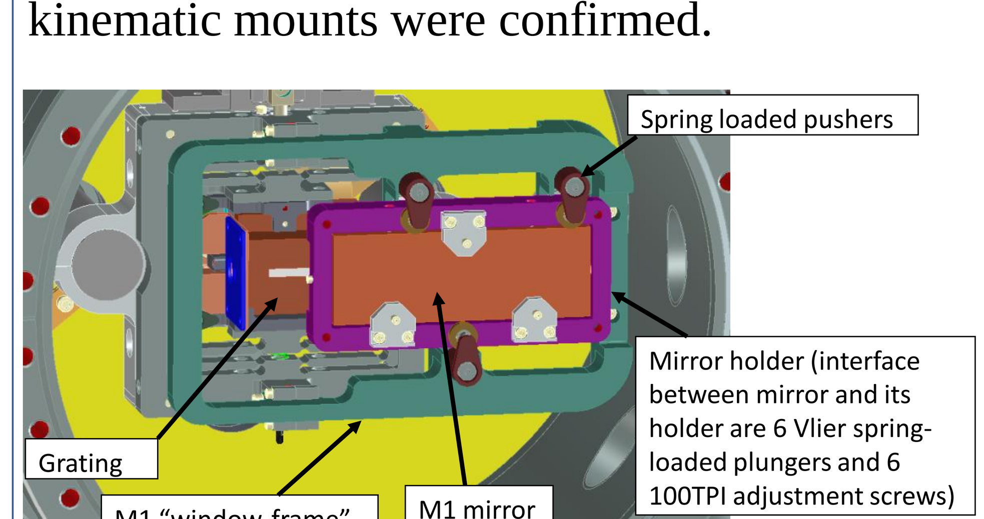


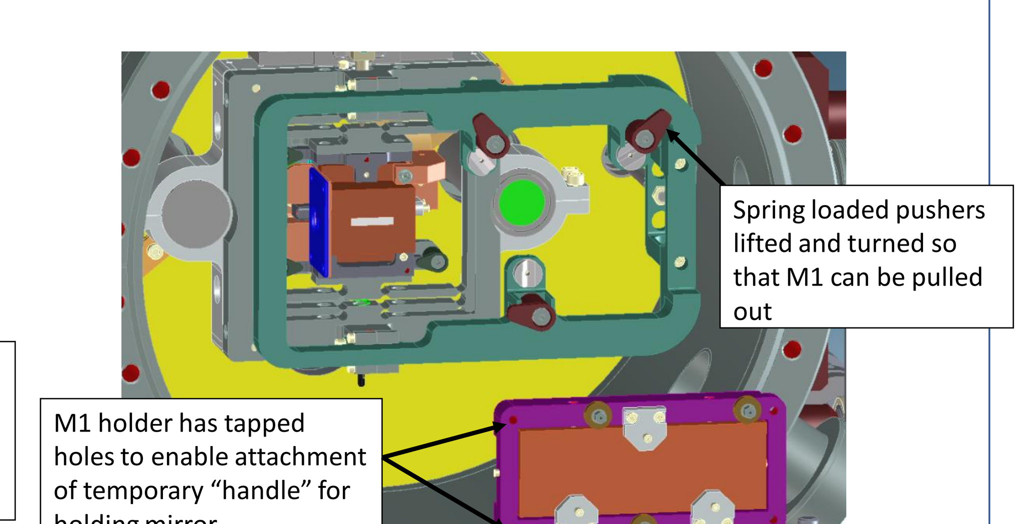
Thermal analysis of system under spontaneous emission radiation

Drift of the M1 pitch angle due to thermal effects was identified as potentially detrimental to performance. We studied M1 pitch angle response to different thermal effects, including conductive heating from M1 motor, overall temperature rise in undulator hall and heating of grating/guard due to spontaneous emission radiation. A 2.7 μrad M1 pitch change is calculated for each deg C of steady-state temperature increase in the motor, requiring carefully managed motor control to minimize motor heating. Other thermal effects are either negligible or manageable.

Optics swap-out

All optics are designed to enable easy removal and replacement. Mirrors are mounted and fiducialized in mirror holders, and holders have kinematic interfaces at mount locations held by spring-loaded pushers. Intermediate fiducialization using separate mount plates provides the ability to adjust alignment of new optics prior to swapping out old optics. Repeatability of the kinematic mounts were confirmed.





Conclusion

A novel two-chamber monochromator is designed for LCLS-I to implement soft x-ray self-seeding. The monochromator is compact to fit next to chicane magnets on a single existing girder, and has 9 different motorized motions to provide steering, energy selection, full retraction, and slit motion. Unique design features include passage holes in optics for the electron beam, easy replacement of optics, and heat extraction from the grating.

The system has been commissioned and has demonstrated soft x-ray self-seeding at LCLS-I with a resolving power of 2000-5000, wavelength stability of 10^{-4}, and an increase in peak brightness by a factor of 2-5 across the photon energy range of 500 to 1000 eV.